EFFECT OF PRE-STRAIN ON MECHANICAL PROPERTIES OF LOW CARBON STEEL

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ABSTRACT

This project is about to study the effect of pre-strain on mechanical properties of low carbon steel. The objectives for this project are to differentiate the influence of various pre-strain on mechanical properties of low carbon steel. This project involves analysis of the mechanical properties of low carbon steel. From the material composition test done, the material that are used is low carbon steel AISI1018. Investigate the influence of pre-strain on the mechanical properties and fitness-for-service of the low carbon steel pipeline subjected to large plastic deformation. Axial tensile pre-strains of 1.5, 5 and 10% were applied to bar-type tensile specimens extracted from the longitudinal direction of the pipe body prior to mechanical testing. Tensile test results revealed that yield strength and tensile strength increased with increasing tensile pre-strain. The rate of increase of the yield strength was greater than that of the tensile strength. The engineering and true stress–strain curves of the virgin and pre-strained materials at room temperature. There was no difference between the virgin material and the pre-strain material in the elastic region; however, strain hardening decreased with increased pre-strain in the plastic zone. Increasing pre-strain increased yield strength but decreased the strain to fracture. The difference in fracture strain between the virgin and pre-strained materials corresponded to the amount of pre-strain applied prior to the tensile tests.

ABSTRAK

Projek ini adalah untuk mengkaji kesan pra-tarikan ke atas sifat mekanikal keluli berkarbon rendah. Objektif bagi projek ini adalah untuk membezakan pengaruh pelbagai pra-tarikan ke atas sifat mekanikal keluli karbon rendah. Projek ini melibatkan analisis sifat mekanikal keluli berkarbon rendah. Dari ujian komposisi bahan yang dibuat, bahan yang digunakan adalah berkarbon rendah keluli AISI1018. Menyiasat pengaruh pra-tarikan ke atas sifat mekanik dan kecergasan untuk perkhidmatan talian paip keluli karbon rendah yang tertakluk kepada ubah bentuk plastik yang besar. pra-tarikan sebanyak 1.5, 5 dan 10% telah digunakan untuk spesimen tegangan jenis bar yang diekstrak dari arah membujur badan paip sebelum ujian mekanikal. Keputusan ujian tegangan mendedahkan bahawa kekuatan alah dan kekuatan tegangan meningkat dengan peningkatkan tegangan pra-tarikan. Kadar peningkatan kekuatan alah adalah lebih besar daripada kekuatan tegangan. Kejuruteraan dan tegangan-terikan benar bahan dara dan pra-tarikan pada suhu bilik. Tidak terdapat perbezaan antara bahan dara dan bahan pra-tarikan di bahagian anjal, walau bagaimanapun, pengerasan terikan menurun dengan peningkatan pra-tarikan dalam zon plastik. Peningkatkan pra-tarikan meningkat menghasilkan kekuatan tetapi menurunkan tarikan untuk mematahkan. Perbezaan dalam tarikan patah antara dara dan bahan-bahan pra-tarikan sejajar kepada jumlah tarikan sebelum ujian tegangan.

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LIST OF SYMBOLS

mm	Millimeter
MPa	Mega Pascal
%	Percent
kN	Kilo newton
σ	Stress
P_o	Operational Pressure
P_d	Pressure on Defect
E	Young Modulus
UTS	Ultimate Tensile Strength
Y	Yield Strength
e	Strain
Cu	Cuprum
H_2	Hydrogen
O_2	Oxygen
^oC	Degree Celsius
kg	Kilogram
GPa	Giga Pascal
K	Kelvin
m	Meter
λ	Modulus Elasticity
ν	Poisson's Ratio
r_d	Curvature of the defect on the right side
r_i	Curvature of the defect on the left side
d_y	Vertical separation
d_x	Horizontal separation

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
ASME	American Society of Mechanical Engineers
AISI	American Iron and Steel Institute
API	American Petroleum Institute
MS	Malaysian Standard
LPG	Liquefied Petroleum Gas
NG	Natural Gas
ANSI	American National Standards Institute
HIC	Hydrogen Induced Cracking
SCC	Stress Corrosion Cracking
SWC	Stepwise Cracking
SOHIC	Stress-Oriented Hydrogen Induced Cracking
SSC	Sulfide Stress Cracking
AF	Acicular Ferrite
FP	Ferrite-Pearlite
MSS	Maximum Shear Stress
VMS	Von Mises Stress
2D	Two Dimension

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter will briefly explain about the introduction of this project. The introduction must be clear before run any project. In this chapter, consists of project background, problem statement, objectives and scope of study. All this information is important before furthering to the analysis and study later.

1.2 PROJECT BACKGROUND

Engineering materials are subjected to a wide variety of mechanical tests to measure their strength, elastic constants, and other material properties as well as their performance under a variety of actual use conditions and environments. The results of such tests are used for two primary purposes such as engineering design (for example, failure theories based on strength, or deflections based on elastic constants and component geometry) and quality control either by the materials producer to verify the process or by the end user to confirm the material specifications (Gedney, 2002).

Because of the need to compare measured properties and performance on a common basis, users and producers of materials use standardized test methods such as those developed by the American Society for Testing and Materials (ASTM) and the International Organization for Standardization (ISO). ASTM and ISO are but two of many standards-writing professional organization in the world. These standards prescribe the method by which the test specimen will be prepared and tested, as well as how the test results will be analyzed and reported.

Study by Baek (2010) investigated the influence of pre-strain on the mechanical properties and fitness-for-service of the API 5L X65 pipeline subjected to large plastic deformation. Axial tensile pre-strains of 1.5, 5 and 10% were applied to plate-type tensile specimens extracted from the longitudinal direction of the pipe body prior to mechanical testing.

Tensile test results revealed that yield strength and tensile strength increased with increasing tensile pre-strain. The rate of increase of the yield strength was greater than that of the tensile strength. The engineering and true stress–strain curves of the virgin and pre-strained materials. There was no difference between the virgin material and the pre-strain material in the elastic region; however, strain hardening decreased with increased pre-strain in the plastic zone. Increasing pre-strain increased yield strength but decreased the strain to fracture. The difference in fracture strain between the virgin and pre-strained materials corresponded to the amount of pre-strain applied prior to the tensile tests (Baek, 2010)

1.3 PROBLEM STATEMENT

Pipelines have been widely used worldwide as one of the most economical and safe ways of transmitting energy. Pipelines transmitting natural gas may be subject to plastic deformation by outside forces such as ground subsidence, ground liquefaction, cold bending and mechanical damage (Hagiwara, 2001). Mechanical properties such as tensile strength, yield strength and fracture toughness of deformed pipelines due to external loads are different from those of straight pipes (Toyama, 2003). Integrity assessment of a pipeline is important for preventing a fracture accident.

In this study, the structural integrity evaluation of a pre-strained pipe was assessed using the low carbon steel procedure which is comprised of three different pre-strain. It is generally accepted that pre-strain alters tensile properties (Fukada, 2002). Tensile tests to

1.5, 5 and 10% pre-strained specimen were performed to evaluate the integrity of a pre-strained pipeline. Based on the composition, the grade for this research referring to American Iron and Steel Institute (AISI) is AISI 1018 with 0.171% of carbon contain. Low carbon steel have low carbon, high formability, weldable, and sheet-metal usage. Low carbon steel AISI1018 used as seamless pipe and also use as gears, brackets, and electrical contacts (Walsh, 1999).

1.4 OBJECTIVES

For this project, several objectives have been developed to be achieved:

1) To study the effect of pre-strain on the mechanical properties of low carbon steel using tensile test.

2) To differentiate the influence of various pre-strain on mechanical properties of low carbon steel.

1.4 SCOPE OF PROJECT

This project concentrated on how the various pre-strains of 1.5, 5 and 10% affect the mechanical properties of low carbon steel. The step consists of:

a) Preparation of material where the carbon steel will be taken from laboratory and then machined to desired specification to make sure the specimen can be processed by the wire-cut machine.
b) There will no pre-stain for 3 specimens (virgin material), then for the other 9 specimens, the pre-strain of 1.5, 5 and 10% test on the specimen.
c) The specimens will be tested by tensile test where the specimens will be test by tensile machine. The parameters that needed to be considered in this process are the tensile stress, the tensile strain, time taken and area reduction.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discusses the literatures that are related to effect of pre-strain on mechanical properties of lo carbon steel. This chapter will review on the material that are used, the machining, and the processes that are used to ready the specimen, the pre-strain processes and lastly the tensile test on the specimen. The sources are taking from journals, articles, and books. Literature review is done to provide information about previous research and that can help to smoothly run this project. All this information is important before furthering to the analysis and study later.

2.2 LOW CARBON STEEL

Steel is derived from iron. Iron ore requires great thermal energy (around 1,500°C) to reduce to its metallic form of iron. The iron is then alloyed with carbon and metals such as nickel or tungsten to produce steel. Steels are described as mild, medium- or high-carbon steels, according to the percentage of carbon they contain. Material used is low carbon steel AISI1018. This low carbon steel is an iron alloy that contains 0.171% carbon. Low carbon steel is very reactive and will readily revert back to iron oxide (rust) in the presence of water, oxygen and ions (Mamlouk, 1999).

2.3 MACHINING

Machining is the broad term used to describe removal of material from a work piece, it covers several processes, which is cutting to get a clearly defined geometry. In this project, we use wire-cut EDM machine.

2.3.1 Wire-cut EDM machine

Wire EDM machining (Electrical Discharge Machining) is an electro thermal production process in which a thin single-strand metal wire in conjunction with de-ionized water (used to conduct electricity) allows the wire to cut through metal by the use of heat from electrical sparks. Machine manufacture is SODICK.

Due to the inherent properties of the process, wire EDM can easily machine complex parts and precision components out of hard conductive materials and make a clean cutting and finishing. Wire EDM machining works by creating an electrical discharge between the wire or electrode, & the work piece. As the spark jumps across the gap, material is removed from both the work piece & the electrode (Port, 1992)

Figure 2.1: Wire-Cut EMD machine setup (SODICK)

(2012)

2.4 TENSILE TEST PROCESS

Engineering stress means load applied to a specimen in a tension or compression test divided by the cross-sectional area of the specimen. The change in cross-sectional area that occurs with increases and decreases in applied load is disregarded in computing engineering stress. It is also called conventional stress. Engineering strain is the change in specimen length divided by the original length. Refer to the definition for strain. True stress is applied load divided by actual area of the cross section through which load operates. It takes into account the change in cross section that occurs with changing load. True strain is instantaneous percent of change in length of specimen in mechanical test. It is equal to the natural logarithm of the ratio of length at any instant to original length (Hosford, 1992).

2.4.1 Pre-strain Test

This project investigates influence of pre-strain on the mechanical properties and fitness-for-service of carbon steel. A universal test machine must be use to apply pre-strains of 1.5, 5 and 10% to the bar-type tensile specimens.

2.4.2 Tensile Test

The strength of material depends on its ability to sustain a load without undue deformation or failure. This property is inherent in the material itself and must determine by experiment. One of the most important tests to perform in this regard is the tension or compression test. Although many important mechanical properties can be determined from this test, it is used to determine the relationship between the average normal stress and average normal strain in many engineering materials such as metals, ceramics, polymers and composites (Hosford, 1992).

Tensile test is used to evaluate the strength of metals and alloys. In this test a metal & plastic sample is pulled to failure in a relatively short time at a constant rate. Before testing, two small punch marks are identified along the specimen’s length. The ability of a material to resist breaking under tensile stress is one of the most important and widely measured properties of materials used in structural applications (Hosford, 1992).

Using the recorded data (load and extension), the engineering stress is found by dividing the applied load by the specimen original cross sectional area in Equation 2.1:

$$\sigma_{eng} = \frac{P}{A_0} \tag{2.1}$$

Where:

σ_{eng} = engineering stress (MPa)

P = applied load (kN)

A_0 = original cross sectional area (mm)

The engineering strain is found by dividing the change in the specimen gage length by the specimen original gage length in Equation 2.2:

$$\varepsilon_{eng} = \frac{\delta}{l_0} = \frac{l-l_0}{l_0} \tag{2.2}$$

Where:

ε_{eng} = engineering strain (mm/mm)

l = gage length (mm)

l_0 = original gage length (mm)

The true stress and true strain of low carbon steel AISI1018 can be found by using the engineering stress and strain value with the Equation 2.3 and 2.4:

$$\sigma_{true} = \sigma_{eng}\left(1 + \varepsilon_{eng}\right) \tag{2.3}$$

Where:

σ_{true} = true stress (MPa)

$$\varepsilon_{true} = \ln\left(1 + \varepsilon_{eng}\right) \tag{2.4}$$

Where:

ε_{true} = true strain (%)

The mechanical properties of a material are related it's behaviour when subjected to continuously increasing elongations up to rupture or fracture. A thorough understanding of a material's mechanical properties is required for engineers if catastrophic failures are to be avoided. Figure 2.2 show the typical ductile material stress-strain diagram with the homogeneous deformation and heterogeneous deformation. The Tensile Test is a common standard test and is a valuable method of determining important mechanical properties of engineering materials (Gedney, 2002).

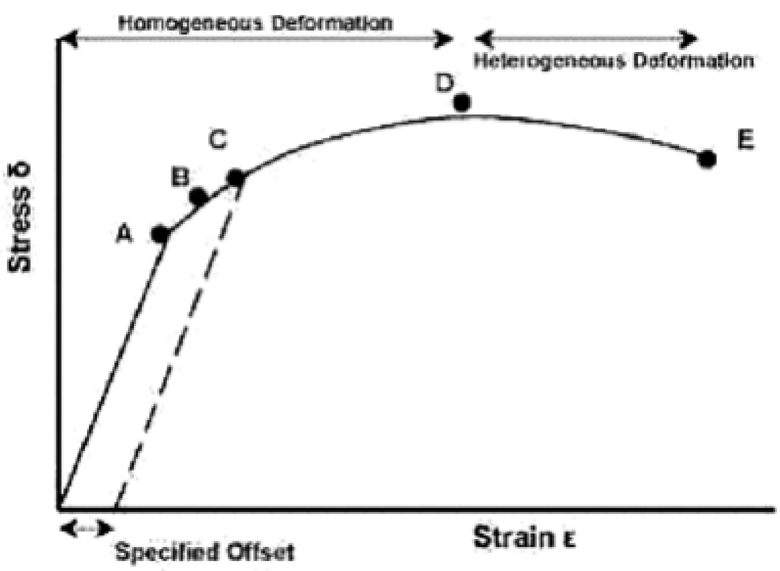

Figure 2.2: Typical ductile material stress-strain diagram

Source: Gedney (2002)

Figure 2.3 show the stress-strain diagram showing yield point elongation and upper and lower yield strengths. The upper yield strengths are higher than the lower yield strengths because of the plastic deformation.

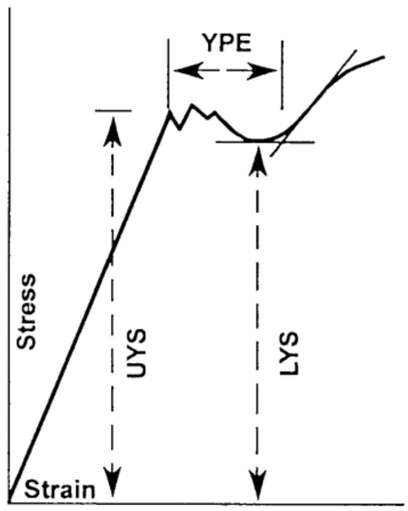

Figure 2.3: Stress-Strain Diagram Showing Yield Point Elongation and Upper and Lower Yield Strengths

Source: ASTM International (2002)

Study by Baek (2010) investigated the influence of pre-strain on the mechanical properties and fitness-for-service of the API 5L X65 pipeline subjected to large plastic deformation. Axial tensile pre-strains of 1.5, 5 and 10% were applied to plate-type tensile specimens extracted from the longitudinal direction of the pipe body prior to mechanical testing.

Tensile test results revealed that yield strength and tensile strength increased with increasing tensile pre-strain. The rate of increase of the yield strength was greater than that of the tensile strength. The engineering and true stress–strain curves of the virgin and pre-strained materials at room temperature are presented in Figure 2.4 and Figure 2.5. There was no difference between the virgin material and the pre-strain material in the elastic region; however, strain hardening decreased with increased pre-strain in the plastic zone, as shown in Figure 2.4. Increasing pre-strain increased yield strength but decreased the strain to fracture. The difference in fracture strain between the virgin and pre-strained materials corresponded to the amount of pre-strain applied prior to the tensile tests (Baek, 2010).

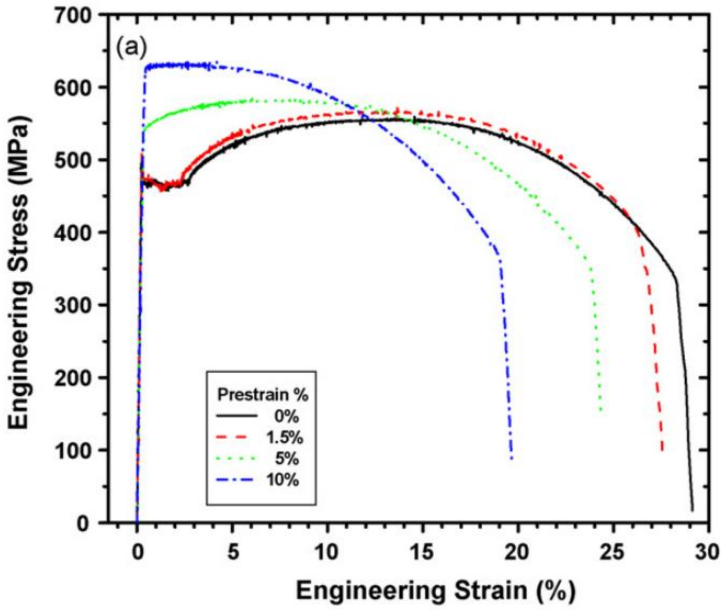

Figure 2.4: Four graph of Engineering Stress (MPa) vs Engineering Strain (%) for pre-strain 0, 1.5, 5 and 10%

Source: Jong-hyun Baek (2010)

The true tensile strength of the pre-strained material was similar to that of the virgin material, illustrated in Figure 2.5. This shows that true tensile strength is minimally affected by pre-strain. The tensile toughness, area under the engineering stress–strain curves up to fracture, was decreased with increasing the pre-strain. The tensile toughness is equal to the work done or energy absorbed by the material while applying pre-strain. Amount corresponding energy expensed during pre-strain in case of the pre-strained material was reduced in the tensile toughness compared to virgin material. It was anticipated from the tensile toughness that the specimens with pre-strain would display low fracture toughness compared of the virgin material (Baek, 2010).

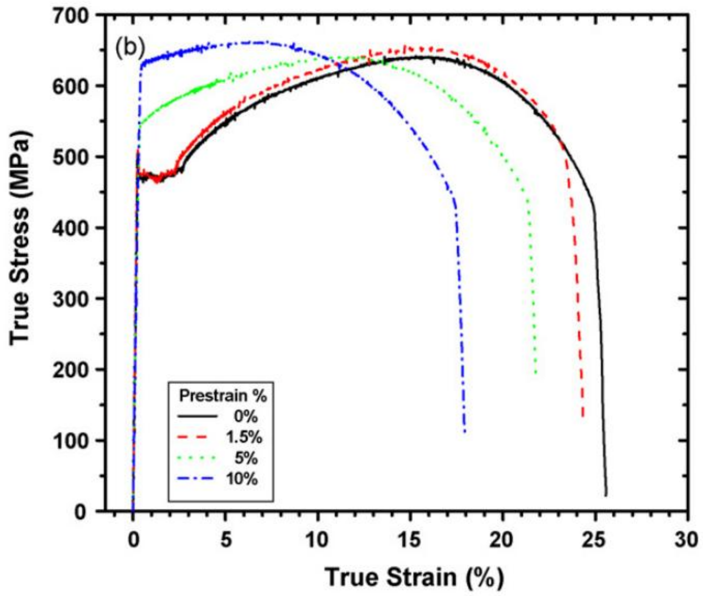

Figure 2.5: Four graph of True Stress (MPa) vs True Strain (%) for pre-strain 0, 1.5, 5 and 10%

Source: Jong-hyun Baek (2010)

Engineering yield strength and tensile strength on virgin material and on materials with tensile pre-strains of 1.5, 5 and 10% are shown in Figure 2.4. Engineering yield strengths and tensile strengths of the materials with 5 and 10% tensile pre-strains were considerably higher than that of the virgin material. The rate of increase in the yield strength was greater than that of the tensile strength. As indicated in Figure 2.5, tensile pre-strain had a significant effect on yield strength (Baek, 2010).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter will describe the procedures of this project regarding of analysis on the cracking in pipeline. Methodology is needed to ensure that the project runs smoothly and the results are accurate based on objective. There are several steps must be followed, to ensure that the objective of the project can be achieved starting from the literature finding until submitting the report.

The analysis starts off with project planning by using a Gantt chart and a flow chart. The flow chart acts as a guide to successfully carry out this case study step by step while the Gantt chart helps to make sure that the project is within its timeframe. The material preparation are done first the check the micro structure low carbon steel. Data acquisition by testing the specimen using tensile test, therefore using appropriate and precise steps is imperative in order to achieve the expected result. Finally the analysis of the whole project may be tabulated and concluded in the following chapter.

3.2 FLOW CHART METHODOLOGY

To achieve the objectives of the project, methodology were constructed base on the scope of product as a guiding principal to formulate this project successfully. The terminology of the work and planning for this project was shown in the flow chart Figure 3.1. This is very important to make sure that the experiment in the right direction.

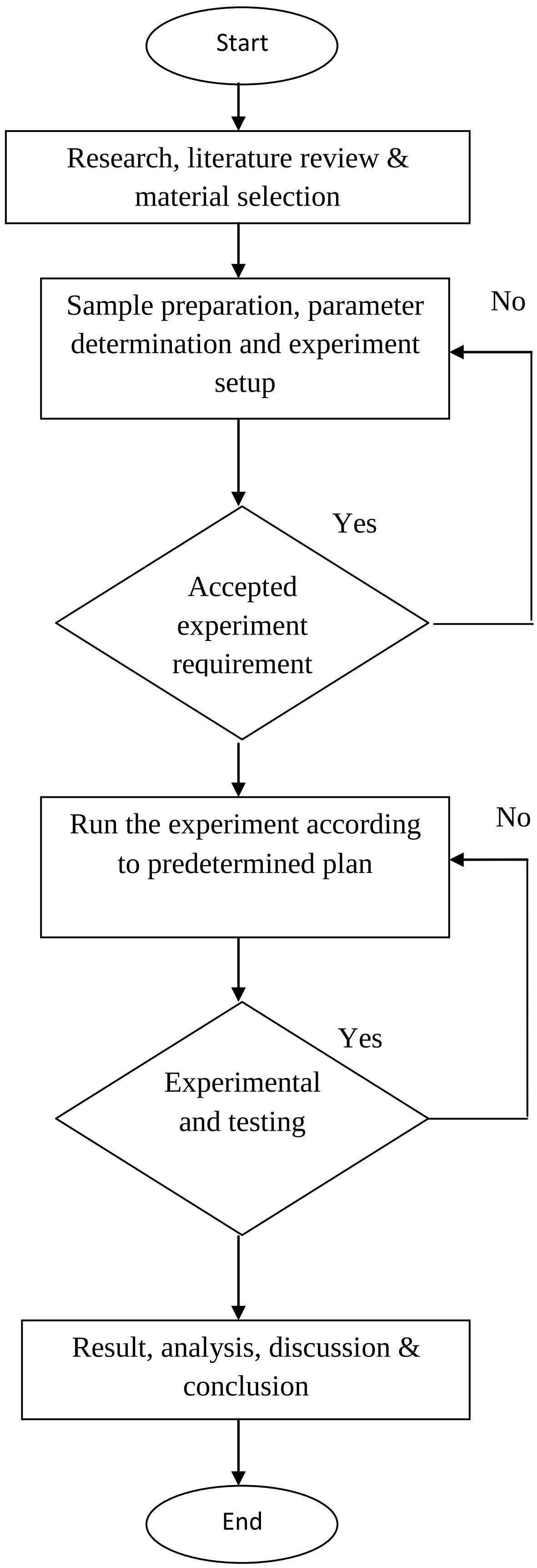

Figure 3.1: Overall flow chart

3.3 PROCEDURE

The procedure to run this analysis is consists of specimen preparation until analysis the result like shown in Figure 3.2.

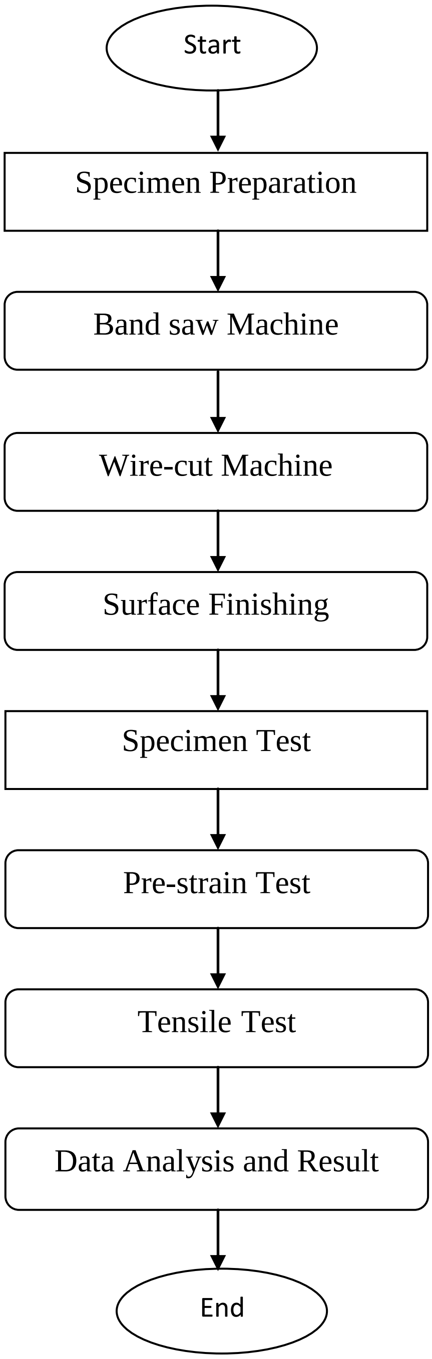

Figure 3.2: Methodology Flowchart

3.4 DESIGN OF EXPERIMENT

To study the effect of pre-strain on mechanical properties of low carbon steel, the important things that needed to be done is the design of experiment. From all the discussions, the things needed to be done are selecting the right material that is low carbon steel. From the material composition test done, the material that are used is low carbon steel AISI1018. Then the machining processes are done to specify the design of the specimen that can be fitted into the tensile test machine.

3.4.1 Specimens preparation

After the design of experiment process end, the material preparations are done. The material that needed to be tested is low carbon steel. There are 12 pieces of raw material of carbon steel that are prepared before machining process to specify the design. The length of each pieces are 200 mm and the thickness is 6 mm.

3.4.2 Material

The material chosen for this experiment is low carbon steel where the carbon content of this steel is only 0.171% and is suitable for low carbon steel specification. Low carbon steel is very reactive and will readily revert back to iron oxide (rust) in the presence of water, oxygen and ions. The type of this steel is low carbon steel AISI1018. It was provided by the shape of plate that has the length of 200 mm and 6 mm of thickness. It has typical traits of steel that are strength, some ductility and easy for machining process. Machining is the broad term used to describe removal of material from a work piece, it covers several processes, which is cutting to get a clearly defined geometry.